P-04-199

Forsmark site investigation

Drill hole KFM04A

Thermal properties: heat conductivity and heat capacity determined using the TPS method and mineralogical composition by modal analysis

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August 2004

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Abstract

Thermal properties on fifteen specimens of drill hole KFM04A, Forsmark, were measured at ambient temperature. The specimens were sampled on three levels in the drill hole at a depth of approximately 109 m, 581 m and 816 m. The investigated rock type is mapped as a fine-grained granite for level 1 (109 m), and medium grained granite for level 2 (581 m) and level 3 (816 m). The mineralogical content was determined by using modal analysis.

The determination of the thermal properties are based on a direct measurement method, the so called “Transient Plane Source Method (TPS)”, Gustafsson (1991) /1/.

Generally, the influence of temperature on the thermal diffusivity was greater than on the conductivity. Thermal conductivity and thermal diffusivity of specimens at different depths at 20°C were in the range of 2.98–3.94 W/(m, K) and 1.29–1.85 mm^2/s respectively.

Contents

1 Introduction

The objective of this investigation was to measure thermal properties of borehole KFM04A, Forsmark, see Figure 1-1, by using the TPS-method /1/. The thermal properties were determined for water-saturated specimens. The specimens, in form of circular discs, were cut from rock cores. The samples were selected based on the preliminary core logging, and with the strategy to primarily investigate the properties of the dominant rock types. The principle of the TPS method is to place a sensor between two rock samples. The sensor consists of a thin metal double spiral, embedded in an insulation material. During the measurement the sensor works both as a heat emitter and a heat receptor. The input data and results of the direct measurement are registered and analysed by the same software and electronics that govern the measurement. The method gives information on the heat conductivity and diffusivity of a material and from this the volumetric heat capacity can be determined, if the density is known.

The test programme follows the activity plan AP PF 400-04-59 (SKB internal controlling document) and is controlled by SP-QD 13.1 (SP quality document).

The samples were water saturated and stored in this condition for 7 days. This yields complete water saturation, whereupon the density and the thermal properties were determined. The specimens were photographed before testing.

Modal analyses, based on point counting using a polarising microscope were performed on 6 specimens that were sampled on the same level as the specimens for thermal properties.

The rock cores arrived to SP in March 2004. The testing was performed during May 2004.

Determination of thermal properties was made in accordance with SKB's method description SKB MD 191.001, version 1.9 (SKB internal controlling document) at SP Fire Technology. Density was determined in compliance with SKB MD 160.002, version 1.9 (SKB internal controlling document) at SP Building Technology and Mechanics.

Modal analyses were performed according to SKB MD 160.001 (SKB internal controlling document) and BMm-P54 (SP quality document).

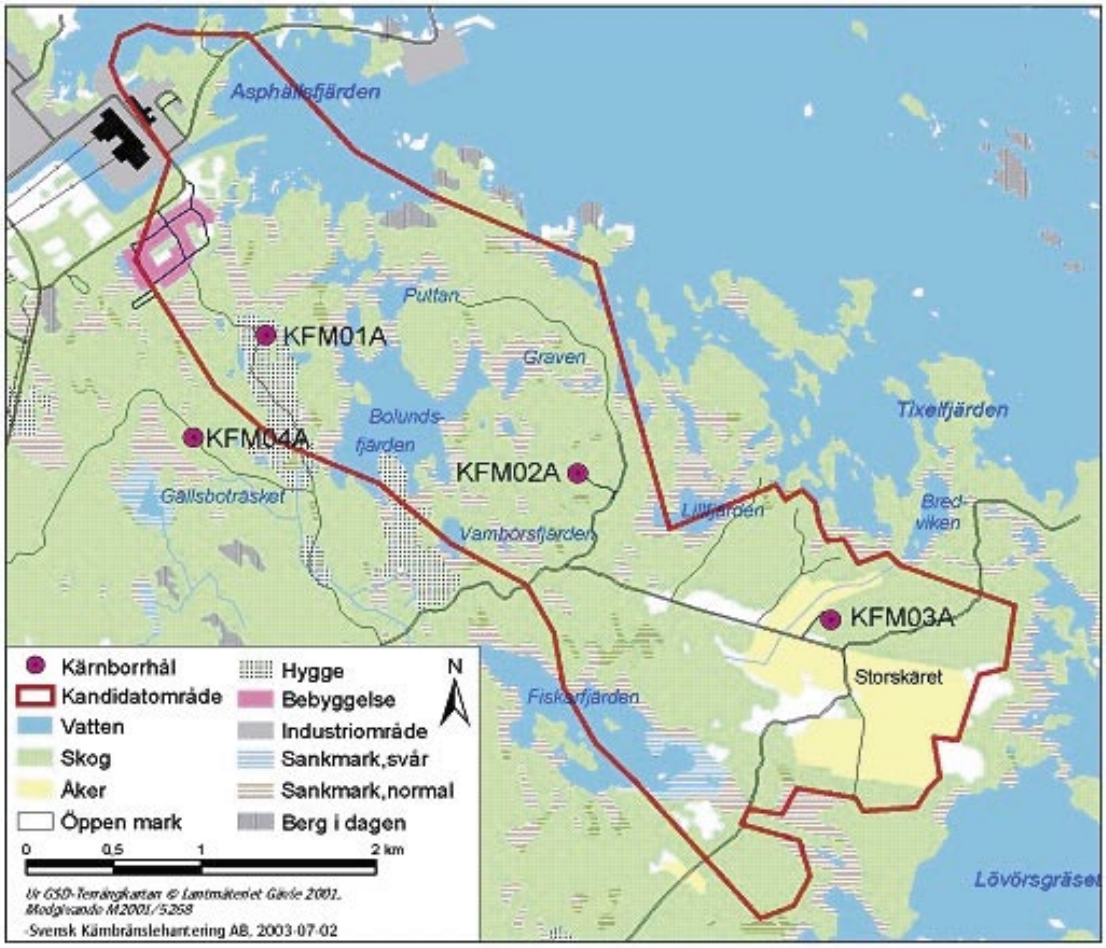

Figure 1-1. *Location of the drill hole KFM04A at the Forsmark site.*

2 Objective and scope

The purpose of the testing is to determine the thermal properties of rock specimens. The results shall be used for the site descriptive modelling of thermal properties, which will be established for the candidate area selected for site investigations at Forsmark.

The samples are from the borehole KFM04A in Forsmark. The specimens were sampled on three levels in the drill hole: 109 m, 581 m, and 816 m.

3 Equipment

Technical devices used for determination of thermal properties were:

- Kapton sensor 5501, radius of the sensor was 6.403 mm, and output of power was 0.7 W. The sensor 5501 fulfils the recommended relation between the radius of sensor and geometry of the samples in /2/.
- TPS-apparatus, Source meter Keithley 2400, Multi-meter Keithley 2000 and bridge, see Figure 3-1.
- PC + Microsoft Office and Hot Disk version 5.4.
- Stainless Sample holder.
- Water bath with immersion heater.
- Immersion heater, Grant, type TD. The accuracy of the thermostat is 0.004°C.
- Hand instrument for control measuring of the water bath temperature.

Technical devices used for modal analyses (point counting) were:

- Leitz Orthoplan optical microscope (inv nr 100276).

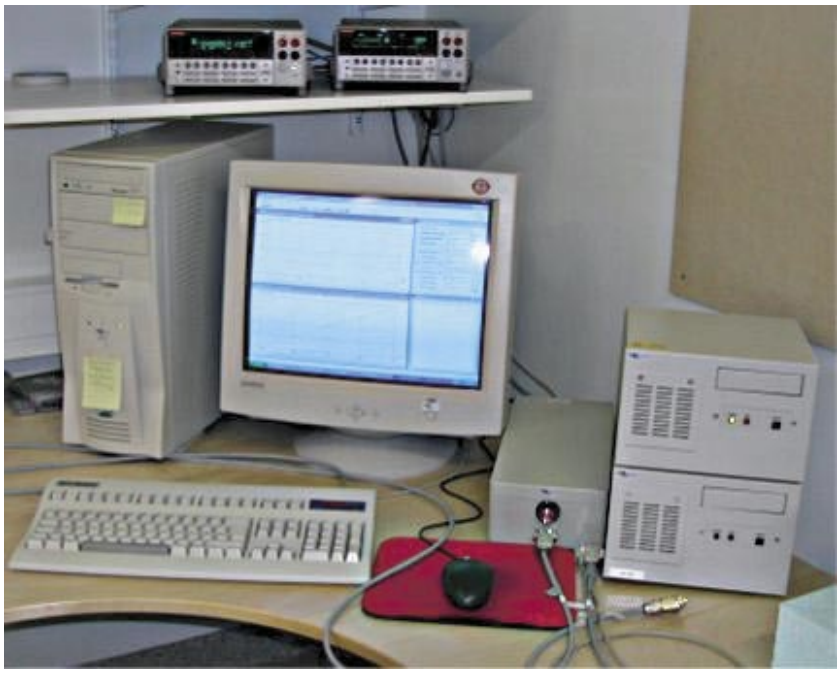

Figure 3-1. *TPS-apparatus with source meter, multi-meter, bridge, and computer.*

Specimen mounting is shown in Figure 3-2.

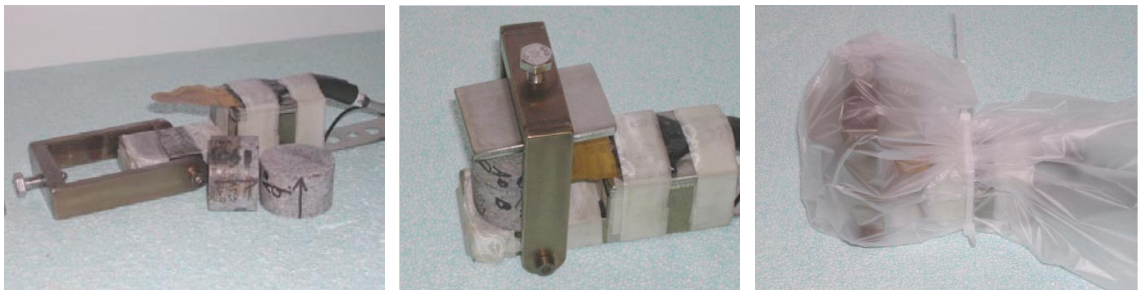

Figure 3-2. *Specimens prior to mounting (left), mounted in stainless sample holder (middle), and sample holder with mounted specimens wrapped in plastic (right).*

4 Execution

Determination of thermal properties was made in accordance with SKB's method description SKB MD 191.001, version 1.9 (SKB internal controlling document) and Hot Disc Instruction Manual /2/ at SP Fire Technology.

Density was determined according to SKB MD 160.002, version 1.9 (SKB internal controlling document) and ISRM /3/. Modal analysis was determined in compliance with SKB MD 160.001 (SKB internal controlling document) at SP Building Technology and Mechanics.

4.1 Description of the samples

Fifteen cores were sampled from three levels of drill hole KFM04A, Forsmark, Sweden. The first level was between 108.8 m and 109.8 m, the second level was between 580.7 m and 581 m, and the third level between 816.2 m and 816.7 m. The thirty specimens, with a thickness of 25 mm each, were selected from the samples at SP, see Figure 3-2. The diameter of the specimens was 50 mm. The rock type, identification marks and depth of the specimens are presented in Table 4-1. Detailed geological description of the rock is given in SKB's BOREMAP of KFM04A and in the SICADA database at SKB.

Shortened sample identification F04A-90V has been used throughout the report.

Table 4-1. Rock type and identification marks (Rock-type classification according to Boremap, July 2004).

Identification	Rock type	Sampling depth (Sec low)
KFM04A-90V-1	Fine-grained granite	108.87
KFM04A-90V-2	Fine-grained granite	108.93
KFM04A-90V-3	Fine-grained granite	108.99
KFM04A-90V-4	Fine-grained granite	109.05
KFM04A-90V-5	Fine-grained granite	109.76
KFM04A-90V-7	Medium grained granite	580.75
KFM04A-90V-8	Medium grained granite	580.81
KFM04A-90V-9	Medium grained granite	580.87
KFM04A-90V-10	Medium grained granite	580.93
KFM04A-90V-11	Medium grained granite	581.00
KFM04A-90V-13	Medium grained granite	816.29
KFM04A-90V-14	Medium grained granite	816.35
KFM04A-90V-15	Medium grained granite	816.40
KFM04A-90V-16	Medium grained granite	816.46
KFM04A-90V-17	Medium grained granite	816.70

4.2 Test procedure

4.2.1 Thermal properties

The following steps were performed:

1. Samples were cut and polished by SP Building Technology and Mechanics.
2. Samples were photographed by SP Building Technology and Mechanics.
3. Samples were water saturated and wet density was determined by SP Building Technology and Mechanics.
4. Samples were sent from SP Building Technology and Mechanics to SP Fire Technology.
5. Thermal properties were determined.
6. Samples were sent from SP Fire Technology to SP Building Technology and Mechanics.
7. Dry density of samples was determined at SP Building Technology and Mechanics.

Thermal properties of water-saturated specimens were measured in ambient air (20°C) . In order to remain water saturation, the samples and the sensor were kept in a plastic bag during the measurement, see Figure 3-2.

Each core pair was measured five times. The time lag between two repeated measurements was at least 20 minutes. The result of each measurement was evaluated separately. The average value of these five measurements was calculated.

Function control of TPS instrumentation was performed according to BRk-QB-M26-02 (SP quality document), see Appendix A.

Measured raw data were saved as text files. Analysed data were saved as Excel files. These files were stored on the hard disc of the measurement computer, and the stored files were sent to the SKB catalogue at the SP network. Further calculations of mean values and standard deviations were performed in the same catalogue.

Thermal properties, density and porosity measurements were performed during April–May 2004.

Dry weight was measured after the specimens had been dried to constant mass according to ISRM /3/ at 105°C. The drying procedure took seven days.

4.2.2 Modal analysis

Modal analysis, based on point counting with at least 500 points counted in each sample, was performed by SP Building Technology and Mechanics.

The analysis was conducted on 6 specimens that were sampled on the same level as the specimens for thermal properties (see Sec low in Table 4-1). The modal analysis was done in order to calculate the thermal properties based on the specimen's mineralogical composition.

5 Results

5.1 Thermal properties

Mean values of measured data, five repeated measurements, are reported in 5.1.1 and 5.1.2 and in the SICADA database (field note no Forsmark 303) at SKB. Values of each separate measurement as described in 4.2 are reported in Appendix B. Furthermore, the total measuring time, the ratio between total measuring time and characteristic time, and the number of analysed points are presented in Appendix C. In a correct measurement the ratio between the total measuring time and the characteristic time should be between 0.4 and 1.

5.1.1 Test results, sample by sample

Sample F04A-90V-01

Figure 5-1. *Specimens F04A-90V-01.*

Table 5-1. Porosity, wet and dry density of specimens F04A-90V-01, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F04A-90V-01			
Sec low: 108.87	2723	2722	0.14

Table 5-2. Thermal properties of sample F04A-90V-01 at ambient temperature.

F04A-90V-01 Sec low: 108.87	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³· K)]
20°C			
Mean value	3.02	1.29	2.34
Standard deviation	0.001	0.004	0.006

Sample F04A-90V-02

Figure 5-2. *Specimens F04A-90V-02.*

Table 5-3. Porosity, wet and dry density of specimens F04A-90V-02, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F04A-90V-02			
Sec low: 108.93	2721	2720	0.13

Table 5-4. Thermal properties of sample F04A-90V-02 at ambient temperature.

F04A-90V-02 Sec low: 108.93	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	2.98	1.38	2.16
Standard deviation	0.003	0.005	0.009

Sample F04A-90V-03

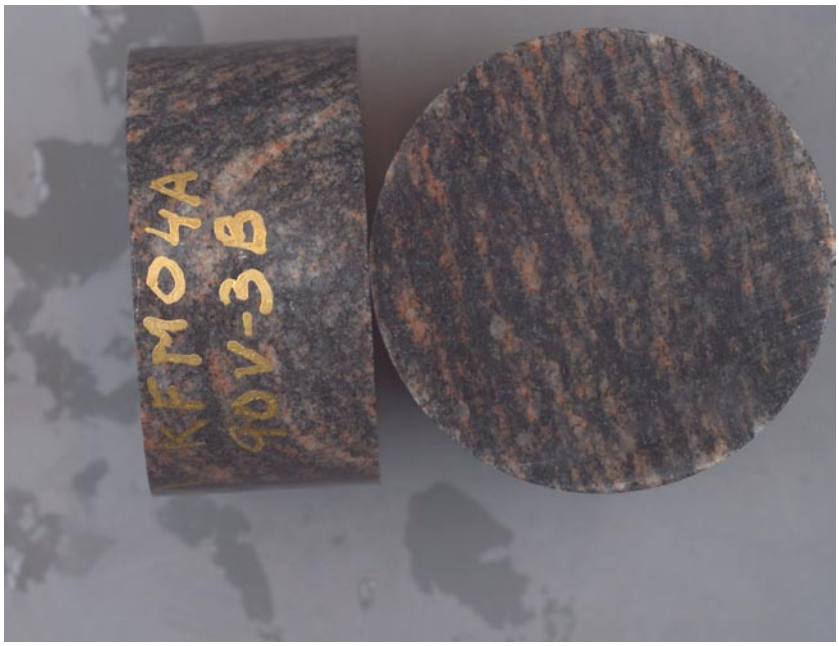

Figure 5-3. *Specimens F04A-90V-03.*

Table 5-5. Porosity, wet and dry density of specimens F04A-90V-03, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F04A-90V-03			
Sec low: 108.99	2719	2718	0.12

Table 5-6. Thermal properties of sample F04A-90V-03 at ambient temperature.

F04A-90V-03 Sec low: 108.99	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	3.04	1.34	2.27
Standard deviation	0.002	0.004	0.007

Sample F04A-90V-04

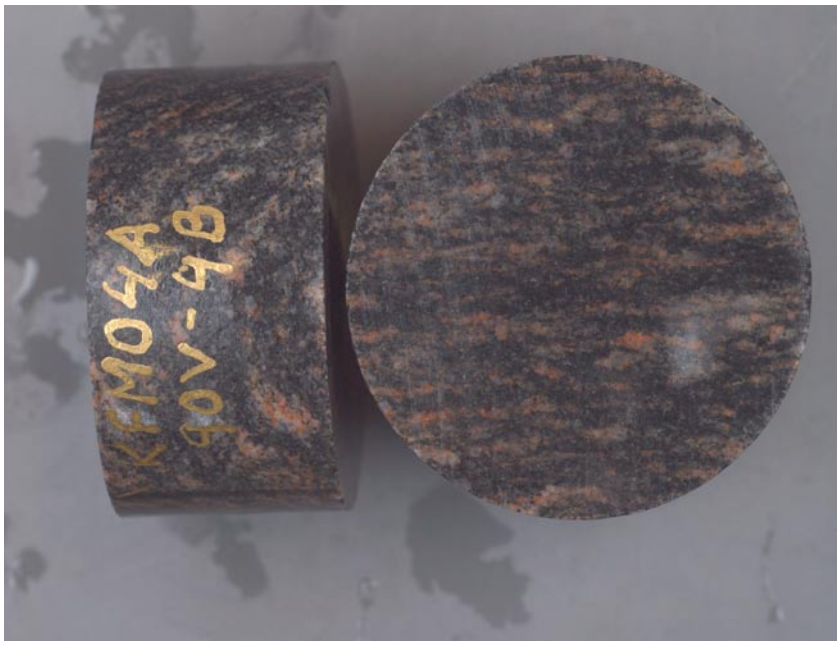

Figure 5-4. *Specimens F04A-90V-04.*

Table 5-7. Porosity, wet and dry density of specimens F04A-90V-04, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F04A-90V-04			
Sec low: 109.05	2719	2717	0.13

Table 5-8. Thermal properties of sample F04A-90V-04 at ambient temperature.

F04A-90V-04 Sec low: 109.05	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	2.98	1.34	2.22
Standard deviation	0.001	0.002	0.003

Sample F04A-90V-05

Figure 5-5. *Specimens F04A-90V-05.*

Table 5-9. Porosity, wet and dry density of specimens F04A-90V-05, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F04A-90V-05			
Sec low: 109.76	2710	2709	0.12

Table 5-10. Thermal properties of sample F04A-90V-05 at ambient temperature.

F04A-90V-05 Sec low: 109.76	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	3.20	1.42	2.25
Standard deviation	0.008	0.012	0.025

Sample F04A-90V-07

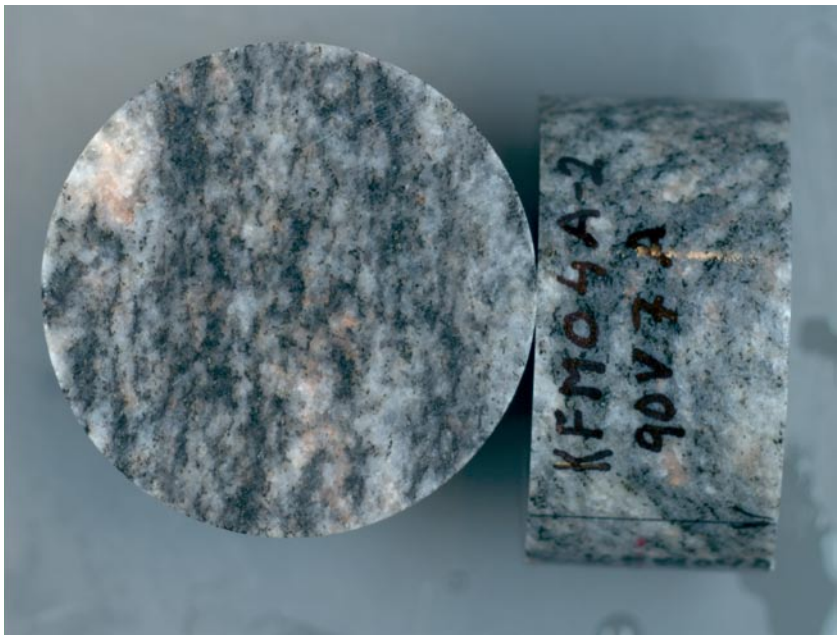

Figure 5-6. *Specimens F04A-90V-07.*

Table 5-11. Porosity, wet and dry density of specimens F04A-90V-07, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F04A-90V-07			
Sec low: 580.75	2649	2645	0.36

Table 5-12. Thermal properties of sample F04A-90V-07 at ambient temperature.

F04A-90V-07 Sec low: 580.75	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	3.54	1.47	2.40
Standard deviation	0.018	0.013	0.010

Sample F04A-90V-08

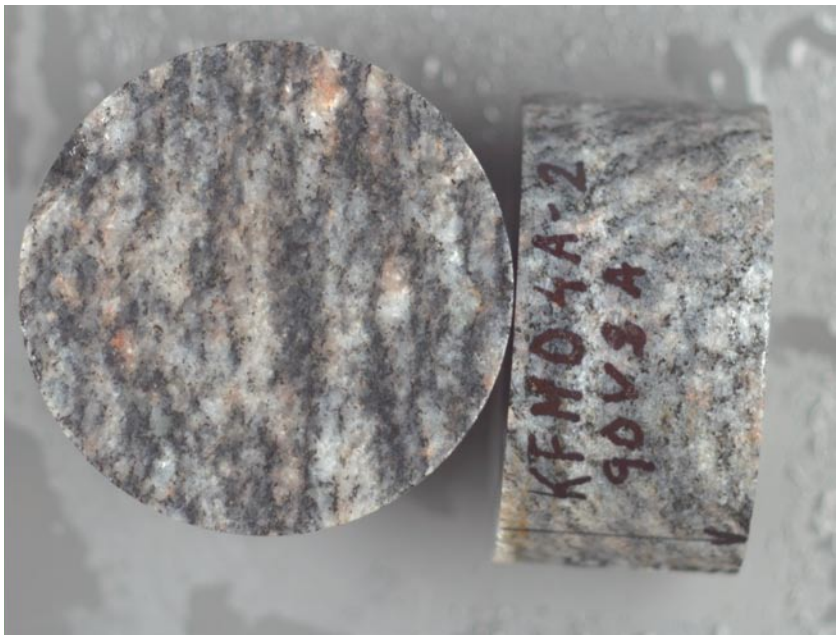

Figure 5-7. *Specimens F04A-90V-08.*

Table 5-13. Porosity, wet and dry density of specimens F04A-90V-08, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F04A-90V-08			
Sec low: 580.81	2652	2648	0.31

Table 5-14. Thermal properties of sample F04A-90V-08 at ambient temperature.

F04A-90V-08 Sec low: 580.81	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	3.94	1.54	2.55
Standard deviation	0.020	0.010	0.005

Sample F04A-90V-09

Figure 5-8. *Specimens F04A-90V-09.*

Table 5-15. Porosity, wet and dry density of specimens F04A-90V-09, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F04A-90V-09			
Sec low: 580.87	2655	2652	0.31

Table 5-16. Thermal properties of sample F04A-90V-09 at ambient temperature.

F04A-90V-09 Sec low: 580.87	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	3.53	1.68	2.10
Standard deviation	0.020	0.009	0.006

Sample F04A-90V-10

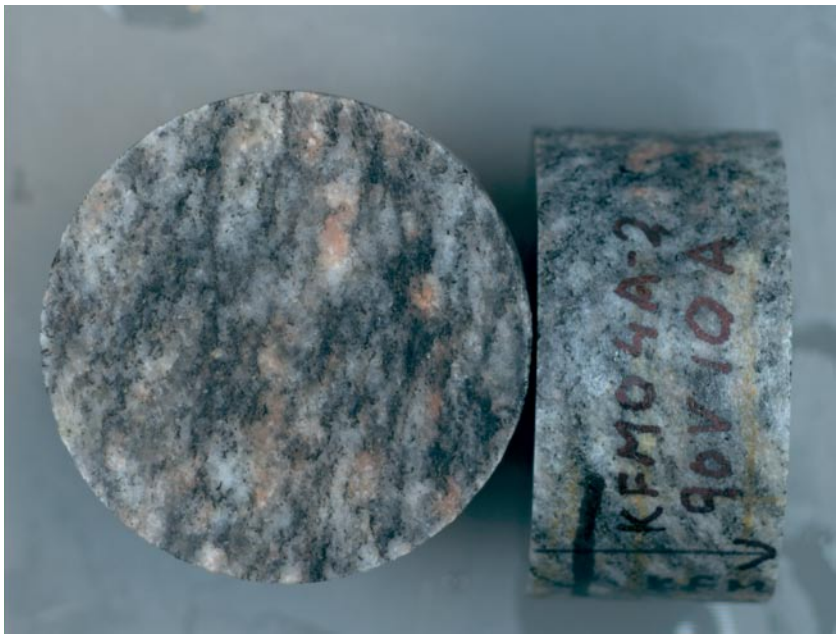

Figure 5-9. *Specimens F04A-90V-10.*

Table 5-17. Porosity, wet and dry density of specimens F04A-90V-10, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F04A-90V-10			
Sec low: 580.93	2657	2654	0.27

Table 5-18. Thermal properties of sample F04A-90V-10 at ambient temperature.

F04A-90V-10 Sec low: 580.93	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	3.83	1.70	2.26
Standard deviation	0.008	0.022	0.026

Sample F04A-90V-11

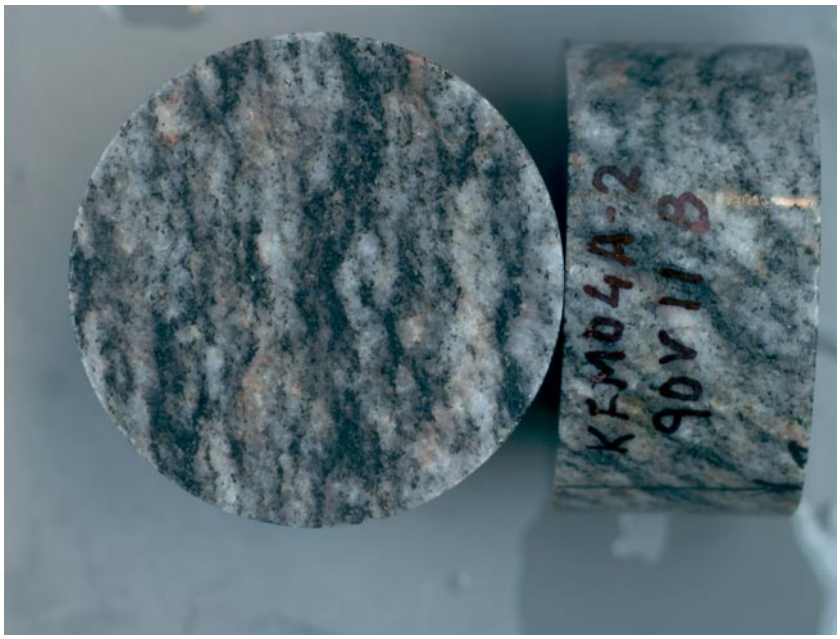

Figure 5-10. *Specimens F04A-90V-11.*

Table 5-19. Porosity, wet and dry density of specimens F04A-90V-11, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F04A-90V-11			
Sec low: 581.00	2658	2655	0.30

Table 5-20. Thermal properties of sample F04A-90V-11 at ambient temperature.

F04A-90V-11 Sec low: 581.00	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	3.67	1.85	1.99
Standard deviation	0.016	0.011	0.017

Sample F04A-90V-13

Figure 5-11. *Specimens F04A-90V-13.*

Table 5-21. Porosity, wet and dry density of specimens F04A-90V-13, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F04A-90V-13			
Sec low: 816.29	2657	2653	0.32

Table 5-22. Thermal properties of sample F04A-90V-13 at ambient temperature.

F04A-90V-13 Sec low: 816.29	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	3.42	1.57	2.18
Standard deviation	0.018	0.011	0.013

Sample F04A-90V-14

Figure 5-12. *Specimens F04A-90V-14.*

Table 5-23. Porosity, wet and dry density of specimens F04A-90V-14, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F04A-90V-14			
Sec low: 816.35	2659	2656	0.37

Table 5-24. Thermal properties of sample F04A-90V-14 at ambient temperature.

F04A-90V-14 Sec low: 816.35	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	3.52	1.65	2.13
Standard deviation	0.015	0.008	0.004

Sample F04A-90V-15

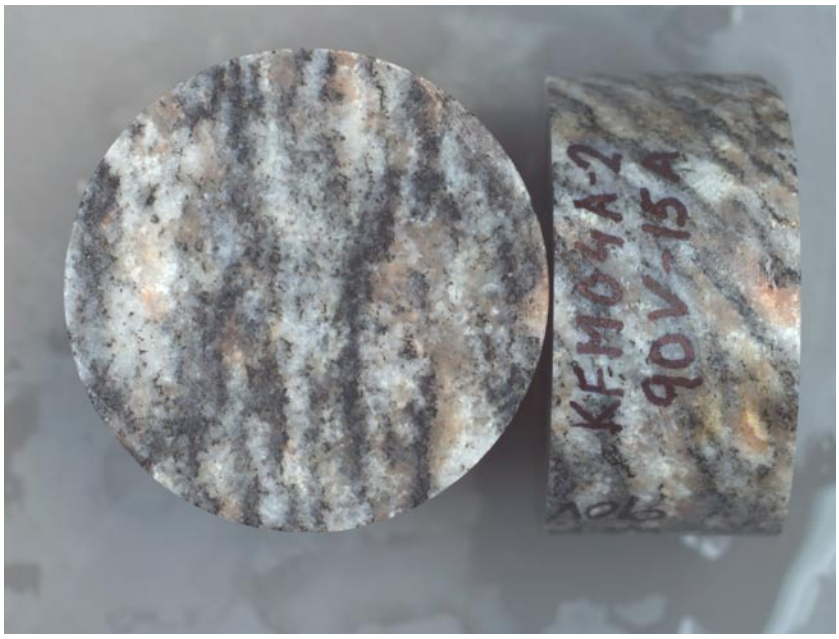

Figure 5-13. *Specimens F04A-90V-15.*

Table 5-25. Porosity, wet and dry density of specimens F04A-90V-15, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F04A-90V-15			
Sec low: 816.40	2655	2652	0.32

Table 5-26. Thermal properties of sample F04A-90V-15 at ambient temperature.

F04A-90V-15 Sec low: 816.40	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	3.56	1.85	1.92
Standard deviation	0.013	0.012	0.011

Sample F04A-90V-16

Figure 5-14. *Specimens F04A-90V-16.*

Table 5-27. Porosity, wet and dry density of specimens F04A-90V-16, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F04A-90V-16			
Sec low: 816.46	2657	2654	0.29

Table 5-28. Thermal properties of sample F04A-90V-16 at ambient temperature.

F04A-90V-16 Sec low: 816.46	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	3.50	1.68	2.09
Standard deviation	0.020	0.015	0.007

Sample F04A-90V-17

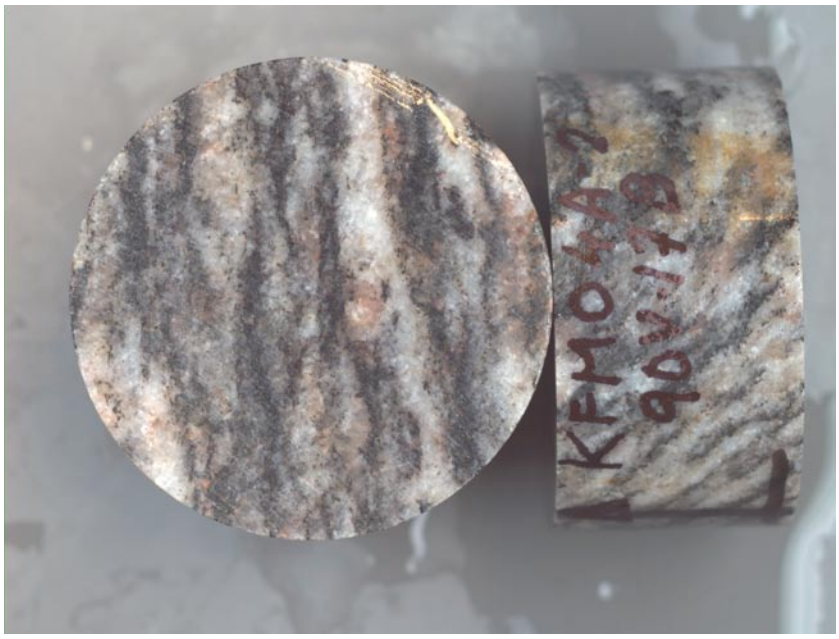

Figure 5-15. *Specimens F04A-90V-17.*

Table 5-29. Porosity, wet and dry density of specimens F04A-90V-17, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F04A-90V-17			
Sec low: 816.70	2658	2655	0.28

Table 5-30. Thermal properties of sample F04A-90V-17 at ambient temperature.

F04A-90V-17 Sec low: 816.70	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
20°C			
Mean value	3.55	1.62	2.20
Standard deviation	0.013	0.018	0.021

5.1.2 Results for the entire test series

Table 5-31 shows the mean value of five repeated measurements of the thermal properties. Standard deviation is displayed in Table 5-32.

Thermal conductivity and thermal diffusivity of specimens at different depths at 20°C were in the range of 2.98–3.94 W/(m, K) and 1.29–1.85 mm^2/s respectively.

Table 5-31. Mean value of thermal properties of samples at 20°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
F04A-90V-01	3.02	1.29	2.34
F04A-90V-02	2.98	1.38	2.16
F04A-90V-03	3.04	1.34	2.27
F04A-90V-04	2.98	1.34	2.22
F04A-90V-05	3.20	1.42	2.25
Mean value, level 109	**3.04**	**1.36**	**2.25**
F04A-90V-07	3.54	1.47	2.40
F04A-90V-08	3.94	1.54	2.55
F04A-90V-09	3.53	1.68	2.10
F04A-90V-10	3.83	1.70	2.26
F04A-90V-11	3.67	1.85	1.99
Mean value, level 581	**3.70**	**1.65**	**2.26**
F04A-90V-13	3.42	1.57	2.18
F04A-90V-14	3.52	1.65	2.13
F04A-90V-15	3.56	1.85	1.92
F04A-90V-16	3.50	1.68	2.09
F04A-90V-17	3.55	1.62	2.20
Mean value, level 816	**3.51**	**1.67**	**2.10**

Table 5-32. Standard deviation of measured values at 20°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
F04A-90V-01	0.001	0.004	0.006
F04A-90V-02	0.003	0.005	0.009
F04A-90V-03	0.002	0.004	0.007
F04A-90V-04	0.001	0.002	0.003
F04A-90V-05	0.008	0.012	0.025
F04A-90V-07	0.018	0.013	0.010
F04A-90V-08	0.020	0.010	0.005
F04A-90V-09	0.020	0.009	0.006
F04A-90V-10	0.008	0.022	0.026
F04A-90V-11	0.016	0.011	0.017
F04A-90V-13	0.018	0.011	0.013
F04A-90V-14	0.015	0.008	0.004
F04A-90V-15	0.013	0.012	0.011
F04A-90V-16	0.020	0.015	0.007
F04A-90V-17	0.013	0.018	0.021

5.1.2.1 Graphical presentation of results

Variation of the thermal conductivity and heat capacity in relation to depth of the samples is shown in Figure 5-16.

Thermal conductivity at 20°C at different depths varied between 2.98 and 3.94 [W/mK] and heat capacity in the same temperature varied between 1.92 and 2.55 [MJ/m3, K].

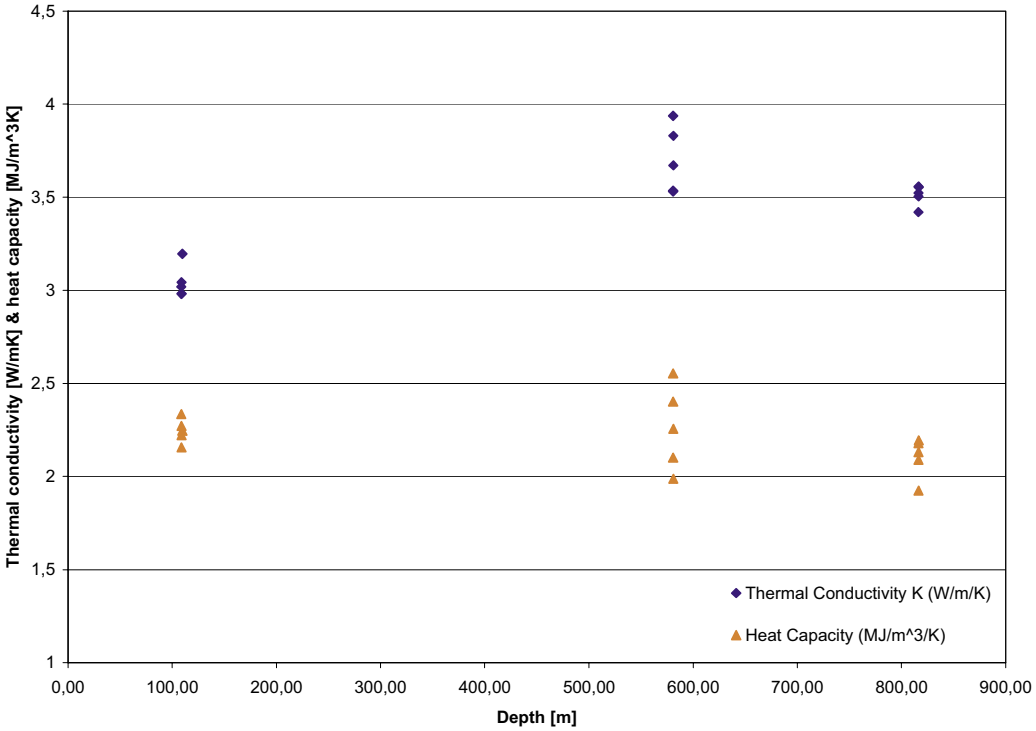

Figure 5-16. *Thermal conductivity and heat capacity at different depths at 20°C.*

5.2 Modal analysis

Modal analyses, based on point counting using a polarising microscope were performed on 6 specimens that were sampled on the same level as the specimens for thermal properties (see Sec up in Table 5-33 and Sec low in Table 4-1). The modal analyses were done in order to calculate the thermal properties based on the specimen's mineralogical composition.

Table 5-33. Mineralogical composition (in vol %) of the six investigated specimens from KFM04A 500 points are counted on each specimen.

Identification	Sampling depth (Sec up)	Qtz	Kfs	Pl	Bt	Amp	Op	As
KFM04A-200-1	108.80	21.4	12.8	47.4	8.6	9.8	–	–
KFM04A-200-2	109.90	27.6	11.0	48.8	8.2	4.4	–	–
KFM04A-200-3	580.69	35.8	22.2	33.6	8.0	–	0.2	–
KFM04A-200-4	581.10	32.8	29.6	36,6	4.0	–	–	0.4
KFM04A-200-5	816.23	35.0	25.4	33.6	4.8	–	0.6	0.4
KFM04A-200-6	816.81	34.0	18.4	42.0	5.4	–	0.2	0.2

The mineral mode is based on point counting using a polarising microscope.

Qtz = Quartz, Kfs = K-feldspar, Pl = Plagioclase, Bt = Biotite, Amp = amphibole, As = Assessory minerals. Assessory minerals are chlorite, epidote and sphene.

5.3 Nonconformities

There were no deviations from the plans.

6 References

/1/ Gustafsson S E. ”Transient plane source techniques for thermal conductivity and thermal diffusivity measurements of solid materials”. Rev. Sci. Instrum. 62 (3), March 1991, American Institute of Physics.

/2/ Instruction Manual Hot Disc Thermal Constants Analyser Windows 95 Version 5.0, 2001.

/3/ ISRM Commission on Testing Methods, ISRM, 1979.

Appendix A

Calibration protocol for Hot Disk Bridge System

Electronics:	Keithley 2400	Serial No 0925167
	Keithley 2000	Serial No 0921454
Hot Disk Bridge:		Serial No 2003–0004
Computation Device:		Serial No 2003–0003, ver 1.4.2
Computer:	Hot Disk computer	Serial No 2003–0003
Test sample:	SIS2343, mild steel	Serial No 3.52
Sensor for testing:	C5501	

Test measurement: 9 repeated measurements on the test sample at room temperature.

Conditions: Power 1 W, Measurement time 10 s

Results

Thermal Conductivity:	13.61 W/(m, K)	± 0.04%
Thermal Diffusivity:	3.519 mm^2/s	± 0.16%
Heat Capacity:	3.867 $MJ/(m^3, K)$	± 0.15%

This instrument has proved to behave according to specifications described in BRk-QB-M26-02.

Borås 26/05 2004

Bijan Adl-Zarrabi

Appendix B

Table B-1. Thermal properties of samples at 20°C.

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
F04A-90V-01			
1	3.02	1.29	2.33
2	3.02	1.30	2.33
3	3.02	1.30	2.33
4	3.02	1.29	2.34
5	3.02	1.29	2.34
F04A-90V-02			
1	2.98	1.38	2.16
2	2.98	1.39	2.14
3	2.98	1.39	2.15
4	2.98	1.38	2.16
5	2.98	1.38	2.17
F04A-90V-03			
1	3.04	1.35	2.26
2	3.05	1.34	2.28
3	3.05	1.34	2.27
4	3.04	1.34	2.28
5	3.04	1.34	2.27
F04A-90V-04			
1	2.98	1.34	2.22
2	2.98	1.34	2.23
3	2.98	1.34	2.22
4	2.98	1.34	2.22
5	2.98	1.34	2.23
F04A-90V-05			
1	3.19	1.44	2.22
2	3.20	1.41	2.27
3	3.20	1.42	2.26
4	3.19	1.43	2.22
5	3.20	1.42	2.26
F04A-90V-07			
1	3.56	1.49	2.39
2	3.55	1.48	2.40
3	3.54	1.47	2.41
4	3.53	1.47	2.41
5	3.51	1.46	2.41
F04A-90V-08			
1	3.96	1.55	2.55
2	3.95	1.55	2.55
3	3.94	1.54	2.55
4	3.93	1.54	2.55
5	3.91	1.53	2.56

Table B-1 (continues). Thermal properties of samples at 20°C.

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
F04A-90V-09			
1	3.56	1.69	2.10
2	3.54	1.68	2.11
3	3.52	1.68	2.09
4	3.52	1.67	2.10
5	3.51	1.67	2.10
F04A-90V-10			
1	3.84	1.71	2.24
2	3.83	1.73	2.22
3	3.83	1.69	2.27
4	3.83	1.68	2.28
5	3.82	1.68	2.27
F04A-90V-11			
1	3.68	1.86	1.99
2	3.68	1.85	1.98
3	3.68	1.83	2.01
4	3.67	1.84	2.00
5	3.64	1.86	1.96
F04A-90V-13			
1	3.44	1.59	2.17
2	3.43	1.56	2.20
3	3.42	1.57	2.18
4	3.40	1.56	2.18
5	3.40	1.56	2.18
F04A-90V-14			
1	3.54	1.66	2.13
2	3.54	1.66	2.13
3	3.52	1.65	2.14
4	3.52	1.65	2.13
5	3.50	1.64	2.13
F04A-90V-15			
1	3.57	1.86	1.92
2	3.56	1.86	1.92
3	3.56	1.84	1.94
4	3.54	1.85	1.91
5	3.54	1.83	1.93
F04A-90V-16			
1	3.54	1.70	2.08
2	3.51	1.68	2.09
3	3.50	1.67	2.09
4	3.49	1.67	2.09
5	3.49	1.67	2.09
F04A-90V-17			
1	3.57	1.65	2.17
2	3.54	1.62	2.18
3	3.56	1.61	2.21
4	3.56	1.60	2.22
5	3.54	1.62	2.19

Appendix C

Table C-1. Total time of measurement, ratio of total time and characteristic time, and number of analysed points at 20°C.

Measurement number	Total time(s)	Total/Char Time	Points
F04A-90V-01			
1	20	0.63	20- 200
2	20	0.63	21- 200
3	20	0.63	19- 200
4	20	0.63	21- 200
5	20	0.62	21- 200
F04A-90V-02			
1	20	0.67	20- 200
2	20	0.67	17- 200
3	20	0.67	18- 200
4	20	0.67	17- 200
5	20	0.67	18- 200
F04A-90V-03			
1	20	0.65	23- 200
2	20	0.65	22- 200
3	20	0.65	21- 200
4	20	0.65	20- 200
5	20	0.65	21- 200
F04A-90V-04			
1	20	0.65	17- 200
2	20	0.65	16- 200
3	20	0.65	20- 200
4	20	0.65	21- 200
5	20	0.65	23- 200
F04A-90V-05			
1	20	0.70	25- 200
2	20	0.68	33- 200
3	20	0.69	33- 200
4	20	0.70	29- 200
5	20	0.69	28- 200
F04A-90V-07			
1	20	0.72	43- 200
2	20	0.72	42- 200
3	20	0.71	47- 200
4	20	0.71	49- 200
5	20	0.71	46- 200
F04A-90V-08			
1	20	0.75	45- 200
2	20	0.75	48- 200
3	20	0.75	49- 200
4	20	0.75	49- 200
5	20	0.74	48- 200

Table C-1 (continues). Total time of measurement, ratio of total time and characteristic time, and number of analysed points at 20°C.

Measurement number	Total time(s)	Total/Char Time	Points
F04A-90V-09			
1	20	0.82	45- 200
2	20	0.81	40- 200
3	20	0.82	43- 200
4	20	0.80	36- 197
5	20	0.81	35- 200
F04A-90V-10			
1	20	0.83	19- 200
2	20	0.84	18- 200
3	20	0.82	20- 200
4	20	0.81	21- 200
5	20	0.82	19- 200
F04A-90V-11			
1	20	0.88	29- 196
2	20	0.83	29- 184
3	20	0.88	28- 198
4	20	0.85	25- 191
5	20	0.87	22- 193
F04A-90V-13			
1	20	0.77	38- 200
2	20	0.76	27- 200
3	20	0.76	25- 200
4	20	0.76	25- 200
5	20	0.73	26- 193
F04A-90V-14			
1	20	0.81	37- 200
2	20	0.81	24- 200
3	20	0.80	27- 200
4	20	0.80	37- 200
5	20	0.80	28- 200
F04A-90V-15			
1	20	0.90	31- 200
2	20	0.90	26- 199
3	20	0.88	23- 197
4	20	0.88	22- 196
5	20	0.88	25- 199
F04A-90V-16			
1	20	0.83	33- 200
2	20	0.81	38- 200
3	20	0.81	30- 200
4	20	0.81	52- 200
5	20	0.81	55- 200
F04A-90V-17			
1	20	0.80	39- 200
2	20	0.79	40- 200
3	20	0.78	46- 200
4	20	0.78	48- 200
5	20	0.78	50- 200